High Performance Product Technology Contributing to Steel Production Equipment

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Steel production is a core technology which underpins the manufacturing industry and continues to evolve in response to industrial trends. High reliability is an absolute requirement for key mechanical components used in the steelmaking process. Efficient and stable steel production relies on the high performance of bearings. JTEKT continues to optimize sophisticated bearing related products, which contributes to improvements in reliability for steelmaking equipment. This paper presents JTEKT technical expertise directed toward fulfilling steelmaking equipment requirements which operate under various conditions and environments.

Key Words*: bearing, steel production, steelmaking process, high reliability, high performance, mechanical components*

1. Introduction

Steel products play a significant role within all industries, including automotive, electrical, marine and infrastructure, and will continue to play an essential role in our society for years to come. Meanwhile, the increased interest in the ecology which has arisen in recent years also applies to steel products. For example, in the automotive field, there is a demand to reduce weight in order to improve fuel efficiency, and there is an increasing percentage of high-tensile steel plate being used. Moreover, magnetic steel sheet essential for the generators and converters used in wind power production and as the iron cores of hybrid car motors, as well as highly-functional steel products with corrosion resistance and wear resistance, are being developed[1]. In the manufacturing processes of such highly-functional steel products (**Fig. 1**), there are requirements for energy-saving features and low environmental burden, not to mention it is important to achieve highly efficient and stable operation of steel production equipment. To achieve such requirements, JTEKT has evaluated the status of bearings, drive shafts, seals and so on out in the field in order to solve the previously mentioned issues, and is engaging in development and improvement activities. This paper will briefly introduce such activities.

2. Manufacturing of iron

2. 1 Pressure roller bearings of sinter pallet cars

Blast furnaces have increased in size in recent years and the number of ultra-large furnaces with capacities of 5 000 m^3 or higher is increasing. In line with the growing size of such furnaces, a need has emerged to increase

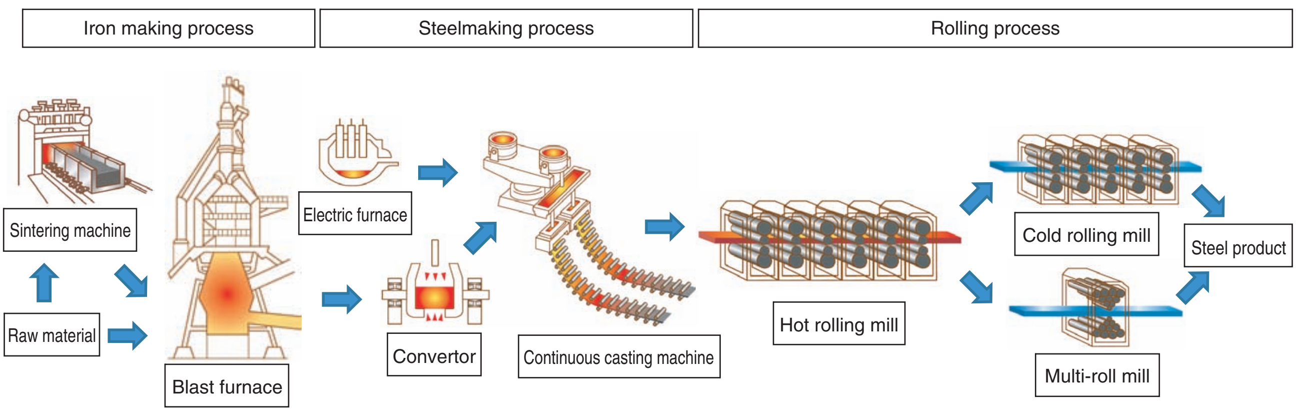

Fig. 1 Steel process flow

the load capacity of sinter pallet cars in order to increase the injected amount of sinter, which is the raw material of steel. Metal bearings have commonly been used in the pressure rollers of sinter pallet cars, however in line with the increase in load capacity, problems have arisen such as the sprocket or sliding portion of metal bearings wearing away in a short period of time, an increase in the oiling frequency of metal bearings and an increase in maintenance costs for replacement of worn parts, etc. As such, JTEKT has modified the metal bearings for pressure rollers to a full complement roller-type design, namely roller bearings (**Fig. 2**, **Fig. 3**) to reduce wear of the sliding portions at the same time as achieving high load capacity and reducing maintenance cost. Moreover, pressure roller bearings had the problem of the outer ring cracking when subjected to heavy load (i.e. weight of the sinter), therefore we conducted a load measurement on the machine itself. The load measurement method used the inner ring which has low hardness to estimate the load from the depth of the brinelling in the inner ring raceway. By correlating the measurement results (**Fig. 4**) and the previous examination data, we estimated the size of the load and the way in which the load was applied. Using the data obtained through measurement, we optimized the bearing internal design which secured outer ring strength (greater outer ring thickness) (**Fig. 5**). Furthermore, by using case hardening steel on the outer ring and improving toughness, the risk of cracking in the outer ring caused by wear or miniscule cracks was reduced.

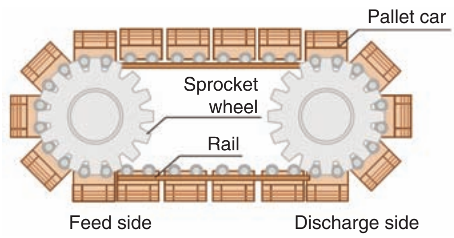

Fig. 2 Configuration of sintering machine

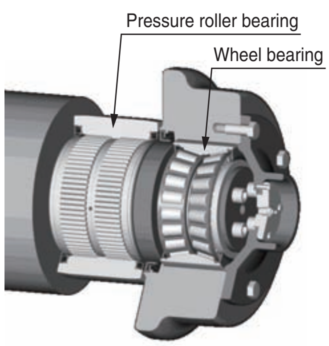

Fig. 3 Pressure roller bearings and wheel bearings

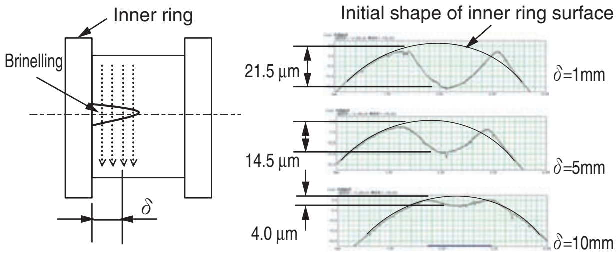

Fig. 4 Measurement of brinelling depth

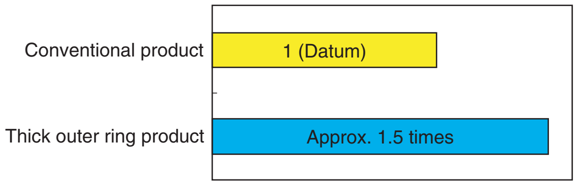

Fig. 5 Comparison of strength between conventional and optimal outer ring thickness

3. Steelmaking

3. 1 Oil/air lubricator for continuous casting machines

JTEKT, rather than merely providing bearings in isolation, also provides total support through the development and commercialization of oil/air lubricators for bearings for application in the steel-making industry. In recent years, oil/air lubrication has become widely adopted in continuous casting machines (**Fig. 6**) within Japan. The main reasons for this is to extend the replacement cycle of segments through improving bearing life and to prevent unforeseen incidents caused by bearing damage. Bearings for continuous casting machines often malfunction and flaking and cracking arise from the worn section inside the bearing. This wear inside the bearing is due to external water penetration, extremely low rotation amounting to only a few revolutions per minute, and insufficient lubricant film formation as a result of heavy load. By adopting oil/air lubrication, it is possible to prevent penetration of water from the outside as the axle box becomes positively pressurized and it is possible to select oil with extreme pressure properties, therefore the bearing will be better lubricated. Generally, a spherical roller bearing is adopted as the stationary bearing of continuous casting bearings. A characteristic of this type of bearing is the two-peaked shape wear which occurs in the raceway due to differential sliding of the roller and raceway. In common environments of use, this form of two-peaked wear is extremely small, therefore rarely causes problems however, as mentioned previously, continuous casting bearings have extremely low speed rotation and insufficient formation of lubricant film due to heavy load, therefore the two-peaked wear intensifies. As such, the highest point of the two-peaks is the point where

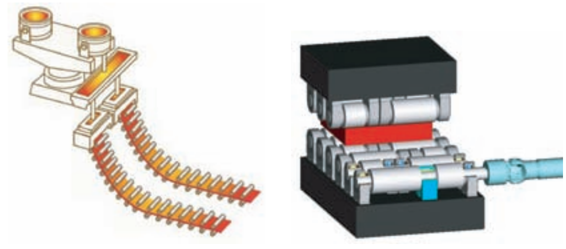

Fig. 6 Continuous casting machines

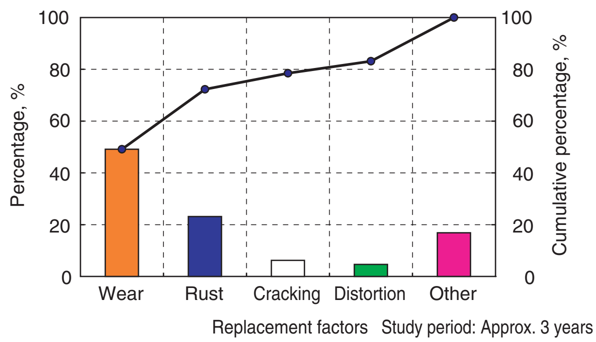

Fig. 7 Causes for replacement of spherical roller bearings

contact stress increases, leading to flaking and, worst case scenario, even resulting in cracking. **Figure 7** shows the causes for replacement of spherical roller bearings. **Figure 8** shows a wear comparison after field test where grease lubrication and oil/air lubrication are adopted respectively on a spherical roller bearing. With the grease lubrication, a significant amount of wear was detected on the outer ring raceway, whereas no wear was found on the oil/air lubrication. Furthermore, rust and flaking occurred when grease lubrication was used, however did not in the case of oil/air lubrication[2).

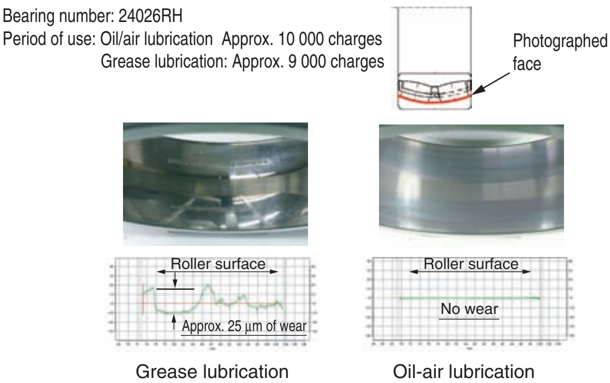

Fig. 8 Wear comparison after field test

Oil/air lubrication is a system of lubricating the bearing by carrying a suitable quantity of oil inside the bearing using air. The oil/air used inside the bearing is returned via the exhaust pipe or discharged through the seal of the bearing housing. In recent years, there has been a strong demand for the seal discharge method, with one reason being that there is no need to install a pipe for recovery, hence reduced layout costs. Another reason is the longer life of seals and the reduction of wear on the seal sliding portions allowing longer intervals between part replacements. The seal discharge method requires a highly-functional seal with a function to maintain the oil and bearing housing internal pressure, as well as a function to enable the stable discharge of oil/air. JTEKT is developing such a seal jointly with Koyo Sealing Techno Co., LTD.

3. 2 Half-ring bearing housing unit

Generally, one mallet-shaped roll is used for the drive roll of continuous casting machines. This mallet-shaped roll adopts a bisectional bearing. JTEKT has integrated the bearing and bearing housing into a single unit, and made the outer ring a half ring (**Fig. 9**) in order to maximize the roller diameter and roller pitch circle diameter. Additionally, we have made the structure compact and sealed in order to maximize the roller length. Through these efforts, high load capacity has been achieved. Moreover, we have installed a water cooling jacket on the top of the bearing housing unit in order to protect the bearing within the bearing housing from external heat such as slab radiant heat. Slabs at temperatures of several hundreds of degrees passes above this water cooling jacket in close proximity (only a few dozen millimeters), therefore cooling efficiency will decline if air bubbles stagnates in this water cooling jacket, which would result in damage to the bearing at an early stage. JTEKT has developed the optimal shape to prevent air bubbles from stagnating within the water cooling jacket and has achieved stable bearing cooling with around 55% of the volume of water used with conventional cooling methods (**Fig. 10**).

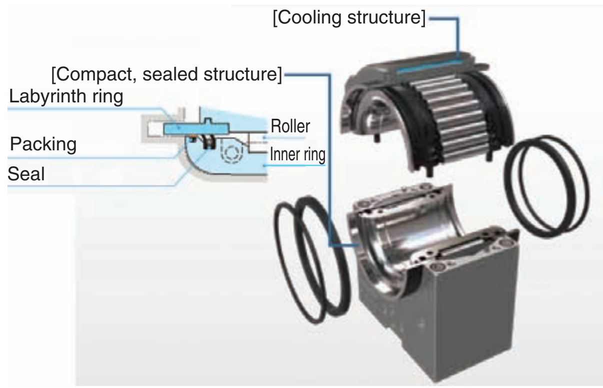

Fig. 9 Configuration of bearing unit with half round outer ring

Fig. 10 Cooling jacket for bearing unit with half round outer ring

4. Rolling mills

4. 1 Long life, high anti-corrosion bearing JHS520

The rolling process is the final stage in which the quality of steel products is determined, therefore there is a demand for roll neck bearings (**Fig. 11**) to be highly reliable. As many rolling mills apply rolling mill coolant throughout the rolling process, it is easy for rolling mill coolant and scale to infiltrate the roll neck bearing, therefore improvements are made to prevent such infiltration. However, because the conditions are extremely harsh, it is not easy to completely prevent this. Particularly in the case of grease sealed bearings for the work roll on cold rolling mills, grease is used continuously and not replaced for an extended period of time, making conditions even harsher. With rolling mill roll neck bearings, in addition to general damage due to rolling contact fatigue, there are issues with early-stage damage caused by rust and infiltration of foreign particles. JTEKT has analyzed the type of damage to the rolling mill roll neck bearing as shown in **Fig. 12**, understood the factors behind the damage and promoted countermeasures from a material point of view[3, 4].

Moreover, in recent years, to respond to extended disassembly inspection cycles of rolling mill roll neck bearings and harsher conditions of usage, a long life, high anti-corrosion bearing which utilizes high-performance material, JHS520, has been developed. The features of JHS520 are shown below.

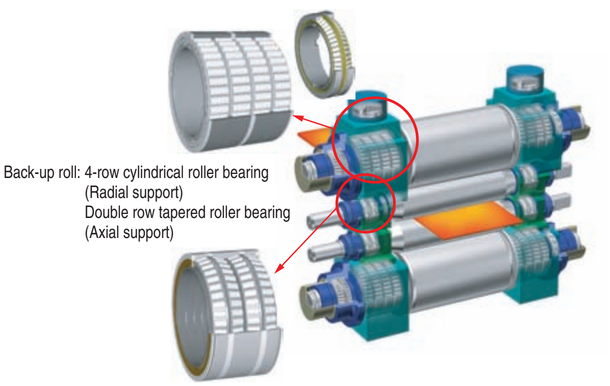

Fig. 11 Rolling mill structure and roll neck bearings (Four-stage rolling mill)

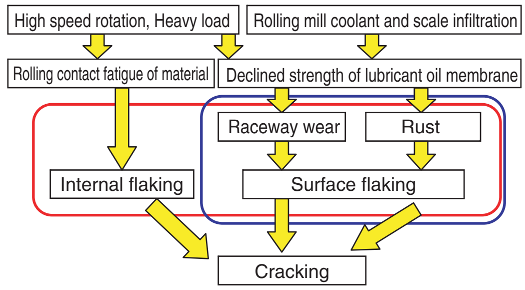

Fig. 12 Failure mode of sealed type four-row tapered roller bearings

	Features
①	Adopted long life, high anti-corrosion steel with optimized Cr and Mo dosage.
②	JTEKT's unique carbon nitride heat treatment to improve anti-corrosiveness and anti-wear properties.

Figure 13 shows the results of a basic performance evaluation on the developed product and an example of its adoption on an actual machine. In the field evaluation, it was proven that the developed product had a life approximately 5 times longer than the conventional product.

4. 2 Replacement of oil film bearing with rolling bearing for back-up roll in a rolling mill

The back-up roll of a rolling mill is subjected to several thousands of tons of rolling reaction force and that rotational accuracy greatly impacts upon the accuracy of the thickness of the plate being rolled. This impact is particularly great in cold rolling mills (including non-ferrous rolling mills) where plate thickness is required to be a high degree of accuracy. As such, since the 1980s it has become standard for rolling bearings to be adopted on the back-up rolls of newly installed tandem cold mills in order to improve rotational accuracy. Moreover, the oil film bearings used in back-up rolls were modified to rolling bearings on rolling mills. In 1984, JTEKT was the first in Japan to use a rolling bearing in the back-up roll of a plate mill and performed dozens of rolling bearing modifications between then and 2013. **Figure 14** is a typical structure when a rolling bearing is modified from oil film bearing specifications. It is common to convert from the oil film bearing, which bears radial load, to a rolling bearing, and use the existing double row tapered roller bearing as is for the axial bearing. In a comparison of plate thickness accuracy before/after rolling bearing modification was made, an improvement of around 40% was obtained on a tandem cold mills. **Figure 15** shows the results of a bench test performed. In regards to the oil film bearing, the thickness of the oil film within the bearing fluctuates significantly depending on changes

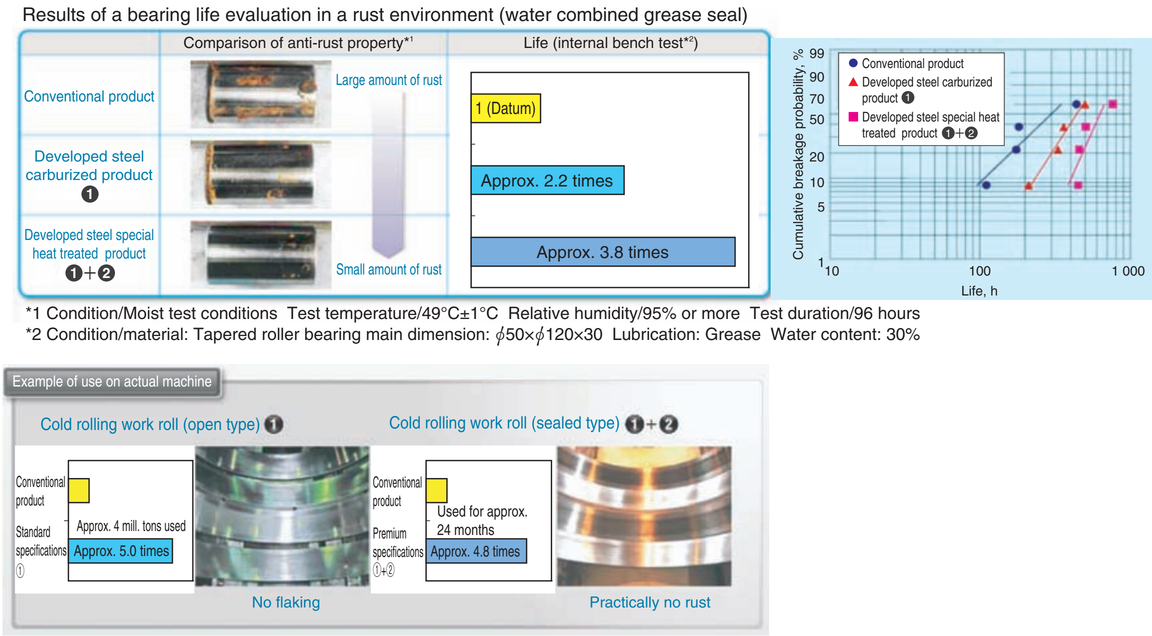

Fig. 13 Performance test result and example of actual operation

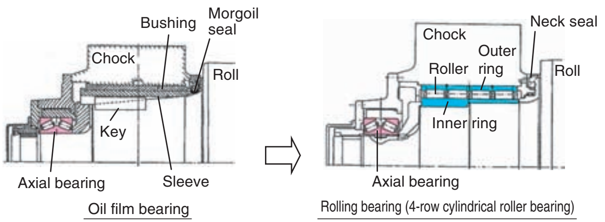

Fig. 14 Replacement of oil film bearing with rolling bearing for back-up roll in multi-roll mill

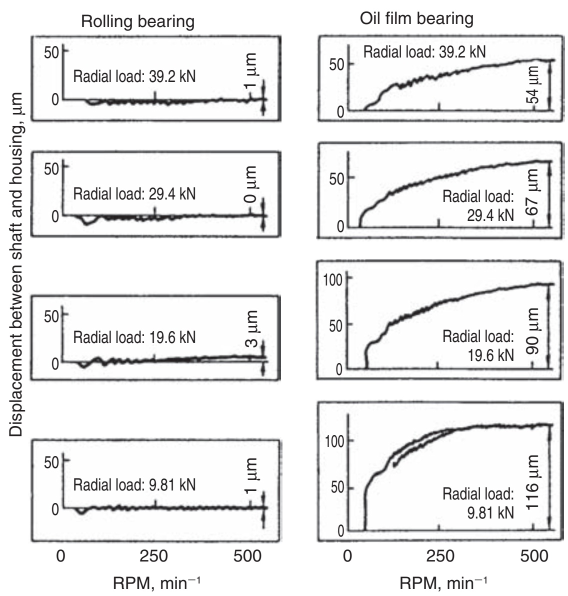

Fig. 15 Displacement between shaft and housing in relation to rotational speeds

in the rotational speed, however with rolling bearings, fluctuation is small, and has been proven to be 3% or less than that of oil film bearings[5].

4. 3 Technology for low temperature rise of roll neck tapered roller bearings

High-speed rolling such as that of hot/cold tandem mills involves the significant issue of being unable to achieve stable operation in the event of roll neck bearing seizure. JTEKT engages in activities to develop a technology which suppresses temperature rise - the cause of seizure in roll neck tapered roller bearings.

One such activity is the development of a low temperature-rise technology based on EHL logic to improve the combining of lubricant on the sliding contact portions of the roller side face and the inner ring rib. By improving the sliding contact portions of the roller and inner ring rib as shown in **Fig. 16**, it was possible to suppress temperature rise and improve anti-searing performance. Consequently, as shown in **Fig. 17** and **18**, the anti-load performance of the improved product was 1.3 times greater than that of the standard product under low speed test conditions and approximately 4 times under high speed test conditions.

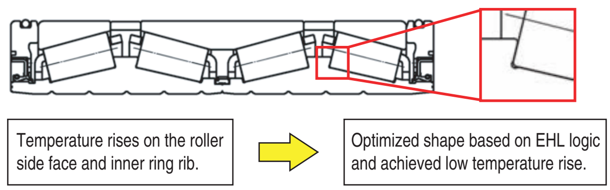

Fig. 16 Roller side face and sliding area on tapered roller bearing

Table 1 Test conditions

Test bearing	45T182211 (ϕ90×ϕ215×110mm)
Lubricant	Grease lubrication (lithium)
Rotational speed	Low speed 920 min^{-1} (constant), high speed 1 840min^{-1} (constant)
Load	Axial load step up

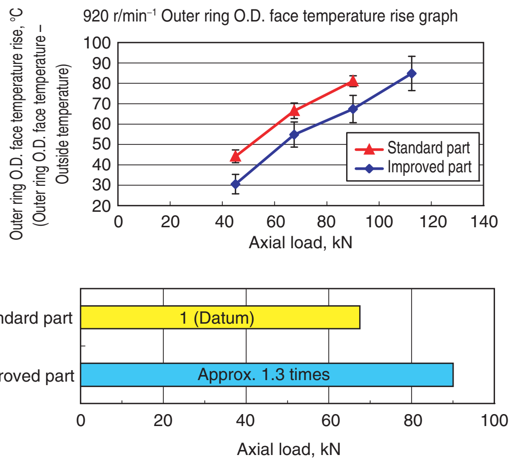

Fig. 17 Axial loading performance at a low speed (920 min^{-1})

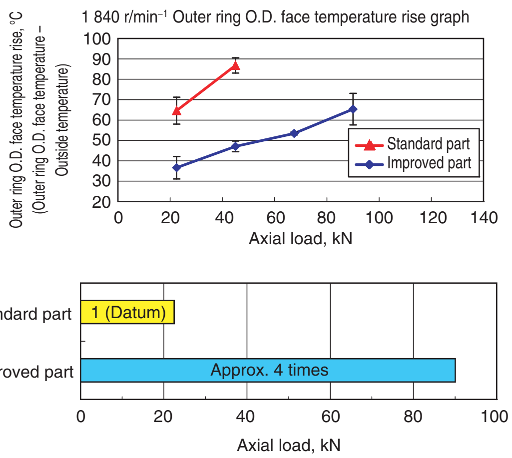

Fig. 18 Axial loading performance at a high speed (1 840 min^{-1})

4. 4 Bearing for multi-roll mill back-up roll JHS210

Recent years have seen an increase in the demand for magnetic steel sheet, an essential material for the generators and converters used in wind power production and as the iron cores of hybrid car motors. The back-up roll bearings used in the multi-roll mills which produce magnetic steel sheets are required to withstand environments with heavy load and insufficient formation of lubricant oil film.

JTEKT has developed a back-up roll bearing, JHS210, for multi-roll mill which has the optimal bearing configuration, as well as a sealed structure (**Fig. 19**, **Fig. 20**). Moreover, we do not only provide back-up roll bearings, but also unit products including shafts and saddles.

	Features
①	High load capacity conversion through a compact seal design
②	Prevention of rolling mill coolant infiltration through a seal plate and discharge of rolling mill coolant through seal lip centrifugal force and a deep groove design
③	Fluoride rubber adopted as the seal material, improving durability at high speed
④	Case hardening steel adopted on the inner ring to improve rolling contact service life under insufficient lubricant oil film formation

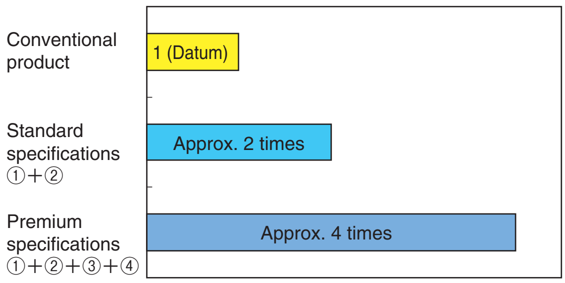

Fig. 19 Bearing service life

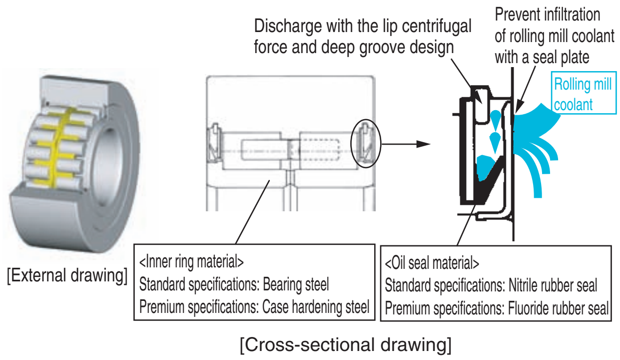

Fig. 20 Multi-roll mill structure and bearing for back-up roll in multi-roll mill

4. 4. 1 Regrinding jig for back-up roll bearings of multi-roll mills

On back-up roll bearings of multi-roll mills the outer ring O.D. face comes directly in contact with the intermediate roll when the outer ring is rotating, therefore the rotational accuracy and roughness of the outer ring O.D. face has a significant impact on plate thickness accuracy and surface quality. In order to secure bearing accuracy, regular regrinding of the outer ring O.D. face is necessary. JTEKT has developed a grinding jig which enables regrinding to be performed at a high accuracy and with ease (**Fig. 21**).

	Features
①	Radial run-out of the bearing has been made extremely small. The engagement gap between the grinding jig and bearing has been eliminated, as well as hydraulic extension has been used for the bearing internal gap to enable regrinding with an extremely small radial run-out.
②	Regrinding work is easier to perform. Jig can be attached and removed with the bearing assembled.

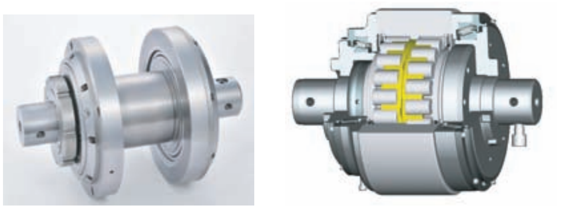

Fig. 21 Bearing-regrinding jig for back-up roll in multi-roll mill

4. 4. 2 Height gauge for bearing of multi-roll mill back-up rolls

For bearings of multi-roll mill back-up rolls, the high-accuracy control of deviation of all assembled bearing heights used in a single shaft is important. JTEKT provides a height gauge which enables high accuracy measurement (**Fig. 22**).

	Features
①	High rigidity, enables high accuracy measurement
②	Outer ring rotational accuracy can be measured
③	Adopts an arbor shape bearing for easy installation/removal of the bearing

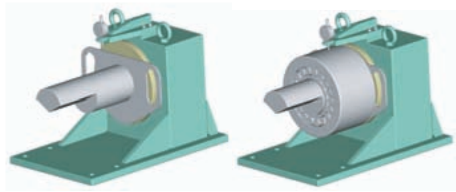

Fig. 22 Measurement for bearing section hight

5. Hyper coupling for prevention of overload on large drive shafts of rolling mills

There is a demand for steel rolling mills to have improved operating rate as well as reduced maintenance man-hours. However, if multiple layers of material are loaded at the same time (**Fig. 23**), an excessive amount of torque will place the entire device under a burden momentarily. In particular, there are cases where the drive shaft and periphery devices break, leading to a decline in operating rate and increase in maintenance man-hours.

As a way to instantaneously disengage this excessive torque, a shear-pin style excess load prevention device has been adopted which utilizes shear failure of a pin. However, this method was accompanied by issues such as the need for regular replacement of the shear pin and the pin replacement work being time-consuming.

JTEKT has developed a hyper coupling for large drive shafts with rotational diameters of ϕ500mm or more. Increase the size of hyper couplings involved issues such as improving the hydraulic holding ability, durability of the torque transmission surfaces and sliding surfaces, improving the idling performance after torque release and so on. The structure of the hyper coupling developed this time was based on the previously developed hyper coupling for small and medium-sized diameters[6] and issues faced when adjusting to suit large diameters were resolved through special surface treatment of the torque transmission surfaces and sliding surfaces, revising the structure of the hydraulic expansion chamber and so on.

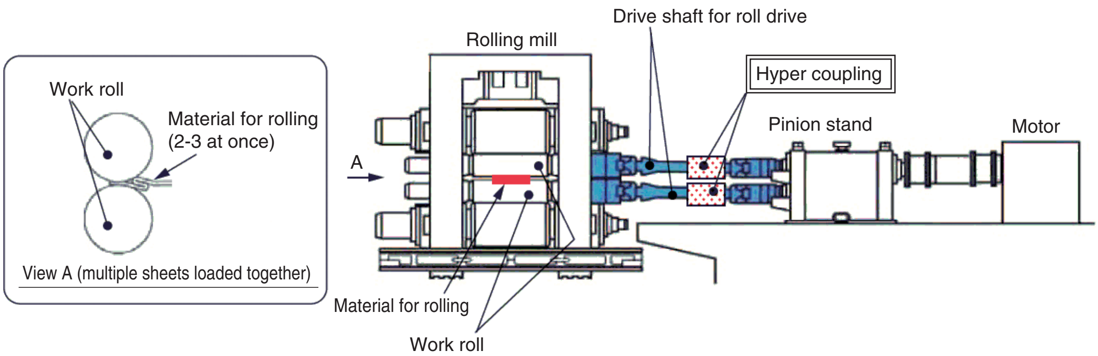

Fig. 23 Layout of rolling mill and location of hyper coupling

5. 1 Structure

The basic structure (**Fig. 24**) and operating rationale of a large hyper coupling is as follows.

(1) A hydraulic pressure expansion chamber is made in the inner diameter of the bore and friction torque is transmitted to the shaft part by expanding with oil pressure.

(2) When excess torque occurs, the torque transmission surfaces slide relatively, oil pressure is disengaged instantaneously, causing the shaft and bore to idle and disengage torque.

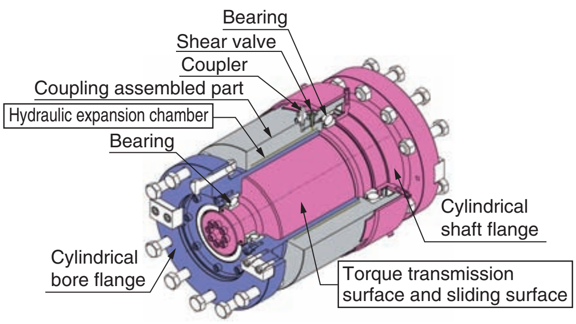

Fig. 24 Configuration of hyper coupling

5. 2 Features

	Features
①	Hydraulic pressure holding ability is improved by around double through improvement of the hydraulic pressure expansion chamber structure.
②	Improvement of the operating accuracy and durability through special surface treatment of the torque transmission surfaces and sliding surfaces.
③	Improvement of oil pressure disengagement performance through establishment of a method to analyze oil pressure disengagement time.
④	Improvement of operating accuracy reliability through optimal design and verification of a large static torsional testing machine.
⑤	Utilize our know-how as a bearing manufacturer and secure idling performance after torque disengagement.
⑥	Able to set operating torque with ease.
⑦	Significantly reduced the recovery time after operation.

5. 3 Performance evaluation for large field sample parts

We fabricated a large field sample and subjected it to a performance test (**Fig. 25**). (Sample size: O.D. ϕ1 090mm, length: 1 500mm)

Figure 26 shows the relationship between oil pressure and torque disengagement. Against the operating setting, the variation of the actual measurement of the large field sample was within ±10%, therefore a torque disengagement equally as stable as that for hyper couplings tailored to small and medium-sized diameters was achieved. Moreover, the actual measurements against each oil pressure were found to display the same trend as the values (theoretical line) found through 3D FEM analysis, thereby confirming consistency with analysis results.

With the previously developed hyper coupling for small and medium-sized diameters (less than ϕ500mm) and the hyper coupling designed for large diameters (ϕ500mm or more) developed this time, our product lineup now covers all drive shaft sizes. A mechanism to protect rolling mill drive systems from excess torque is essential for stable operation, and we believe that hyper couplings contribute significantly to this.

Fig. 25 Large sized torsional tester

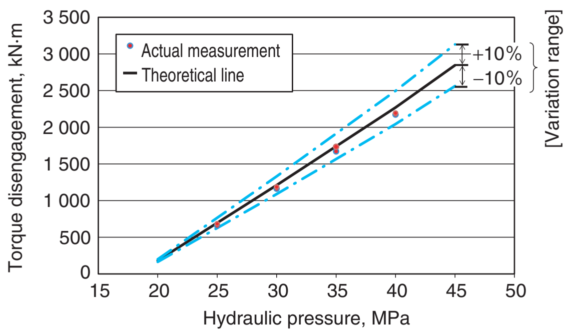

Fig. 26 Relationship between oil pressure and torque disengagement

6. Conclusion

This paper has introduced JTEKT's technical endeavors in the area of steel production equipment. JTEKT keeps visiting customers in order to meet the various requirements for steel production equipment. Through these activities, we can realize the methods by which customers handle bearings and drive-shafts, and instruct the customers in the disassembly. We also measure load and vibration to realize the usage conditions of bearings. JTEKT will continue these activities and promote the development of products which contribute to safer and more operable environments.

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